5.0 Steps of the Screening Risk Assessment

There are three main components of the overall site closure plan: the groundwater model, the screening risk assessment, and the closure plan itself (Figure 4). The activities required to prepare the risk assessment includes the following main steps identified in Section 5.1 and substeps identified in Section 5.2.

5.1 Four Main Steps of Screening Risk Assessment

The screening risk assessment has four main steps:

A. ***Use method paper***: The method paper outlined the proposed procedures to be followed during the risk assessment. This has already been completed in the form of progress reports (IT, 1999) and the work developed earlier in 2000 through conversations with DOE, the Alaska Department of Environmental Conservation (ADEC), the U.S. Fish and Wildlife Service (USFWS), and the Aleutian/Pribilof Island Association (A/PIA).

B. ***Establish technical basis, including best professional practices:*** This report describes the technical basis for the risk assessment (as outlined in the method paper), and includes revisions to refine the exposure volumes, diets, and other technical parameters. The five substeps, each of which has its own work elements, are listed in Section 5.2.

C. ***Prepare screening risk assessment report:*** This constitutes the remainder of the current work.

D. ***Respond to review comments***

Main activity (Step B) is further divided into substeps that flow into the site closure plan. Note that detailed explanations of each of the inputs or elements to the screening risk assessment are found in Attachment A to this report.

5.2 Five Substeps of Screening Risk Assessment (Step B)

The five substeps necessary for defining the technical basis for the risk assessment (Main Step B) are briefly described below:

1. ***Define conditions:*** This means that the radionuclides of potential concern (ROPCs) are identified, locations of potential release are predicted, ocean substrates are defined, current velocity and direction are known, and dilution is calculated.

2. ***Set exposure scenarios:*** This refers to the volume of water available for dilution. There are two proposed volumes of marine water considered in this report: small (i.e., in the close vicinity of the potential release) and large (i.e., a large portion of the Bering Sea).

3. ***Select receptor scenarios:*** This refers to the human receptors that will be used and the diets that will be assumed. Both subsistence and commercial-catch exposures will be assumed.

4. ***Input data for model elements into equations:*** This refers to selection of the bioconcentration factors (BCFs), cancer morbidity risk coefficients (CMRCs) (formerly termed cancer slope factors), and dietary consumption rates.

5. ***Show and discuss risk per unit of radionuclide released:*** This is a graphical representation and detailed discussion of risk posed by the various radionuclides. Tables 1 through 5 show the process by which a risk factor will be calculated for each radionuclide in each scenario. This factor is called the radionuclide risk factor (RRF) because it gives the risk from one unit of flux. Flux is the rate of release of material, in this case radionuclides (i.e., 1 picocurie [pCi] of each radionuclide per day). The RRF will be multiplied by the predicted flux to calculate the risk from that radionuclide under that scenario. Tables 1 through 5 show not only the chain of computation but also provide example outputs. The resulting risk values are included in Figures 5 through 13.

5.3 Eleven Elements

As explained earlier, most substeps have one or more types of inputs or elements associated with the conceptual model. These 11 elements are:

1. ROPCs
2. Locations of releases
3. Seabed substrates
4. Transport by currents
5. Dilution, including plume
6. BCFs
7. Human receptors
8. Distribution of diet
9. Fraction of contaminated diet
10. CMRCs
11. Limits to cancer risk

An expanded treatment of each element is provided in Appendix A. A brief description is provided for each element followed by an exposition of current knowledge and the implementation for using the data per the above steps and substeps.

5.4 Anticipated Exposure Volumes

The two relative sizes of exposure volumes of sea water were identified in Section 5.2. Predicted releases from each site into a small volume were combined to calculate risk among scenarios. Additionally, combined releases into a volume approximately the size of the Aleut culture and communication area were used to calculate overall risk. This section further explains and justifies these volumes.

5.4.1 Small Volumes

The small volumes are modeled plumes in which substances potentially released to the ocean floor are dispersed. The groundwater model predicts releases over a range of distances from shore. For plume modeling, it was assumed that the releases occur at a point midway between the 5^{th} and the 95^{th} percentiles of the distances predicted by the groundwater model. Those distances are approximately 3.0 kilometers (km) from the shoreline for Cannikin, 2.0 km for Long Shot, and 2.0 km for Milrow.

Depthwise, the small volumes are located in a range from the shoreline at 0 ft deep to the predicted outer limit of releases, near the 300-ft depth contour for Cannikin in the Bering Sea and Milrow in the Pacific Ocean, and around 180 ft for Long Shot in the Bering Sea. This represents a horizontal expanse of about 3.8 km for Cannikin, about 4.4 km for Long Shot, and about 5.5 km for Milrow. The size of each small volume was calculated by using a dispersion model that takes into account the location of the release, wave action, and currents. For more details, see the element on dilution, including plume, in Appendix A, Section A.6.0.

One variant for Milrow assumes that kelp occupies the entire volume and retards the current by one-third. For details, see the element on seabed substrates in Appendix A, Section A.4.0.

5.4.2 Large Volume

A large volume of sea water was also used for dilution and exposure modeling. This volume represents the Aleut culture and communication area. Thousands of square miles of surface and about half-a-million cubic kilometers of marine waters are contained in this very large volume. For details, see the element on dilution, including plume, in Appendix A.

5.5 *Calculational Process and Expected Output*

The standard method of performing a risk assessment for radionuclides in water is to begin with concentrations of constituents (i.e., radionuclides in seawater), calculate the estimated concentrations in the diet of human receptors by applying water-to-biota uptake factors, calculating the lifetime dose by multiplying the concentration by the food ingestion rate, and computing the risk by using CMRCs expressed as risk per pCi of radionuclide exposure during a lifetime. Risks from individual radionuclides can be added to compute a cumulative risk.

To estimate the concentration in seawater, it is necessary to know the flux of individual radionuclides into the sea. However, that information is classified. Therefore, neither the concentration nor the flux of radionuclides is stated in this report. As a result, the risk assessment presented in this report includes several unclassified terms. These terms are combined to form the RRF, which is the annual risk per picocurie per day (pCi/d) of radionuclide flux:

$$\text{RRF} = \text{BCF} \times \text{DIL} \times \text{FrC} \times \text{AIR} \times \text{CMRC},$$

Where:

RRF = Radionuclide risk factor (cancer risk/year per pCi/d)
BCF = Bioconcentration factor (liters per kilogram)
DIL = Dilution factor (pCi/liter per pCi/day = days per liter)
FrC = Fraction contaminated
AIR = Annual food ingestion rate (kilogram/year)
CMRC = Cancer morbidity risk coefficient (lifetime risk/pCi)

The terms of this equation are illustrated and explained in Tables 1 through 5 and the accompanying text. The RRF is analogous to the CMRC, but the RRF relates risk to daily flux rather than to a lifetime. The RRF can be used to make calculations of the risk from the hydrogeologically predicted radionuclide flux.

The RRF can also be used to handle many radionuclides at the same time and to calculate cumulative risks. Because the unit of risk is the same for all radionuclides (i.e., lifetime excess cancer risk), risks can be summed for a few or all radionuclides. The RRFs will be calculated for each radionuclide in each diet scenario. The RRFs will be applied to the output of groundwater modeling and to calculate the cumulative risk for each exposure scenario. The cumulative risks will be compared to a 10^{-6} risk threshold as described in Section 5.7, "Application of Calculational Process." This information will be used in the site closure report.

Table 1 outlines the groups of calculations that were done. Tables 2 through 5 present the steps in each set of calculations. Examples are also given in Tables 2 through 5 using the radionuclides tritium, strontium-90, and cesium-137. These radionuclides were chosen for illustrative purposes because estimates of their yields had been used for preliminary studies. Table 6 presents an example of the RRFs for Long Shot that were used to calculate radionuclide flux.

Table 1
Outline of the Calculation Process for Radionuclide Risk Factors

Radionuclide	Cumulative Dietary Bioconcentration Factor (Table 2)	Factor to Calculate Radionuclide Concentration in Diet (Table 3)	Annual Ingestion Exposure Factor for All Dietary Items Combined (Table 4)	Calculation of Radionuclide Risk Factor for Each Radionuclide (Table 5)
Tritium Carbon-14 Chlorine-36 Strontium-90 Yttrium-90 Iodine-129 Technetium-99 Cesium-137 Samarium-151 Europium-152 Gadolinium-152 Uranium-234 Uranium-236 Uranium-238 Neptunium-237 Plutonium-239 Plutonium-240 Plutonium-241 Americium-241	Computes a cumulative dietary bioconcentration factor for each scenario by summing the product of dietary fractions and BCFs.	Combines cumulative dietary bioconcentration factor with dilution factor and fraction of diet that is contaminated to calculate dietary concentration factor.	Combines dietary concentration factor with annual ingestion rate to yield annual ingestion exposure factor for each radionuclide.	Combines annual ingestion exposure factor with cancer morbidity risk coefficient to yield a radionuclide cancer risk factor for each radionuclide. The radionuclide risk factor is multiplied by the annual average daily radionuclide flux to yield the annual excess cancer risk.

The process for selecting radionuclides to be included in this risk assessment is described in Section A.2.0. The cumulative BCF is used to calculate the concentration of radionuclides in the contaminated portion of the diet from the concentration in seawater. The steps in the cumulative BCF calculation are presented in Table 2. These steps are to multiply the BCF for each radionuclide and each food item by the fraction of the diet represented by that food item and sum the results.

Table 2
Calculation of Cumulative Dietary BCF

Dietary item	Parameter	Example Radionuclides (19 radionuclides are considered)		
		Tritium	Strontium-90	Cesium-137
Marine fish	Fraction of marine fish in diet[a] Published BCF[b] (L/kg) Partial dietary BCF[c](L/kg)	0.9 1.0 0.9	0.9 0.926 0.833	0.9 100 90
Marine mammals	Fraction of marine mammals in diet[a] Published BCF[b](L/kg) Partial dietary BCF[c](L/kg)	0.05 1.0 0.05	0.05 1.0 0.05	0.05 100 5.0
Crustaceans	Fraction of crustaceans in diet[a] Published BCF[b](L/kg) Partial dietary BCF[c](L/kg)	0.01 1.0 0.01	0.01 2.0 0.02	0.01 30 0.3
Mollusks	Fraction of mollusks in diet[a] Published BCF[b](L/kg) Partial dietary BCF[c](L/kg)	0.01 1.0 0.01	0.01 10 0.1	0.01 30 0.3
Plants (including kelp)	Fraction of plants in diet[a] Published BCF[b](L/kg) Partial dietary BCF[c] (L/kg)	0.01 1.0 0.01	0.01 5.0 0.05	0.01 50 0.5
Other (nonmarine) food	Fraction of other foods in diet[a] CF (0 for non-marine foods) Partial dietary BCF[c] (L/kg)	0.02 0 0	0.02 0 0	0.02 0 0
Total diet	Cumulative dietary BCF[d] (L/kg)	0.98	1.05	96.1

[a]Dietary distribution for subsistence diet, mostly marine fish (see Table A-6):

Fish	0.9
Mammals	0.05
Crustaceans	0.01
Mollusks	0.01
Plants	0.01
Other (non-marine)	0.02

[b]From the appendix to the report, Table A-7
[c]Dietary fraction multiplied by BCF
[d]Sum of partial dietary BCFs

L/kg = Liters per kilogram

The cumulative dietary BCFs are multiplied by a dilution factor (Section A.6.2.2) and the fraction of the diet that is assumed to be contaminated (Section A.10.0). This computation is illustrated in Table 3.

Table 4 uses the output from Table 3 (dietary concentration factor [DCF]), the average daily ingestion rate, and a conversion factor to convert from ingestion per day to ingestion per year as inputs. The DCF was multiplied by the average daily ingestion rate (assumed to be 1.25 kilogram per day

Table 3
Factor to Calculate Radionuclide Concentration in Diet

Radionuclide	Cumulative BCFs (L/kg)	Dilution Factor[a] (d/L)	Fraction of Diet That is Contaminated[b]	Dietary Concentration Factor (d/kg)
19 Selected radionuclides	Table 2: Dietary fraction of each item is multiplied by the bioconcentration factor of each item, and the products are summed.	DIL converts radionuclide flux (pCi/d) to radionuclide concentration in water (pCi/L).	Fraction of diet that is contaminated (FrC) is calculated from the sizes of the plume and the fishing or hunting area and the density of marine food.	Cumulative BCF multiplied by the dilution factor and the fraction of diet that is contaminated: DCF (d/kg) = Σ(DF × BCF) × DIL × FrC.
Example:				
Tritium	0.98	1.11E-11	3.6E-04	3.90E-15
Strontium-90	1.05	1.11E-11	3.6E-04	4.18E-15
Cesium-137	96.1	1.11E-11	3.6E-04	3.83E-13

BCF = Bioconcentration factor
DIL = Dilution factor
FrC = Fraction of diet that is contaminated
DCF = Dietary concentration factor
DF = Fraction of diet made up by each dietary item
pCi/d = Picocuries per day
pCi/L = Picocuries per liter
L/kg = Liters per kilogram
d/L = Day per liter

[a]Calculated for the Long Shot plume as described in Attachment A, Section A.6.2.2.
[b]Calculated as described in Attachment A, Section A.10.4.

[kg/day] for Native Alaskans and 0.86 kg/day for consumers of commercial catch; see Section A.8.2) and the conversion factor of 365 days per year to yield the annual ingestion exposure factor (IEF). The output of Table 4 constitutes input to Table 5.

Table 5 uses the annual ingestion exposure factor from Table 4 along with the CMRC to calculate the RRF. The CMRC is a factor that is used to predict the annual contribution to the probability of morbidity from cancer resulting from exposure to radiation over a 70-year lifetime. The CMRC is adjusted for dietary absorption of ingested radionuclides and for variability of sensitivity to carcinogens during different life stages (see Attachment A, Section A.11.0). Therefore, it accounts for exposure of both children and adults.

As an example, RRFs for the nineteen radionuclides and the three diet scenarios for the Long Shot exposure volume are presented in Table 6.

Table 4
Annual Ingestion Exposure Factor for all Dietary Items Combined

Radionuclide	Dietary Concentration Factor (d/kg)	Annual Ingestion Rate (kg/y)	Calculation of Annual Ingestion Exposure Factor (d/y)
19 Selected radionuclides	Dietary concentration factor from Table 3.	Annual ingestion rate (daily ingestion rate multiplied by days/year): AIR (kg/y) = IR (kg/d) × 365.25 days per year = 1.25 kg/d × 365.25 d/y = 4.55E+02 year.	Annual ingestion exposure factor is the dietary concentration factor multiplied by annual ingestion rate: (d/y) = DCF (d/kg) × AIR (kg/y). When multiplied by flux, this yields the annual dietary exposure (pCi/year).
Example: Tritium Strontium-90 Cesium-137	 3.90E-15 4.18E-15 3.83E-13	 4.55E+02 4.55E+02 4.55E+02	 1.78E-12 1.90E-12 1.74E-10

d/µg = Day per kilogram
kg/y = Kilogram per year
AIR = Annual ingestion rate
IR = Ingestion rate

Table 5
Calculation of Radionuclide Risk Factor for Each Radionuclide

Radionuclide	Annual Ingestion Exposure Factor (d/y)	Cancer Morbidity Risk Coefficient (cancer risk/pCi)	Calculation of Radionuclide Risk Factor (cancer risk/y per pCi/d)
19 Selected radionuclides	Annual ingestion exposure factor from Table 4.	Cancer morbidity risk coefficient is the probability of excess cancers per pCi of radionuclide ingested in a 70-year lifetime (excess cases/pCi). Source of CMRCs is EPA (2001).	Radionuclide risk factor for lifetime excess cancer risk is the annual ingestion exposure factor multiplied by the cancer morbidity risk coefficients: RRF [(excess cases/y)/(pCi/d)] = IEF (d/year) × CMRC (excess cases/pCi). When multiplied by flux (pCi/d), yields annual contribution to lifetime excess cancer risk (excess cases per year).
Examples: Tritium Strontium-9 Cesium-137	 1.78E-12 1.90E-12 1.74E-10	 6.51E-14 9.53E-11 3.74E-11	 1.16E-25 1.31E-22 6.52E-21

d/y = Day per year

Table 6
Radionuclide Risk Factors for Long Shot Exposure Volume

Radionuclide	Diet for Exposure Scenarios		
	Subsistence Consumption, Mostly Marine Fish [(risk/y)/(pCi/d)]	Subsistence Consumption, Mostly Marine Mammals [(risk/y)/(pCi/d)]	Consumption of Commercial Catch [(risk/y)/(pCi/d)]
Tritium	1.16E-25	1.16E-25	3.60E-27
Carbon-14	6.14E-20	6.15E-21	2.34E-21
Chlorine-36	3.07E-24	6.85E-24	8.88E-26
Strontium-90	1.31E-22	1.39E-22	7.40E-24
Yttrium-90	2.31E-21	1.50E-21	4.21E-22
Technetium-99	4.17E-22	2.81E-22	6.51E-23
Iodine-129	1.13E-20	7.42E-21	1.78E-22
Cesium-137	6.52E-21	6.52E-21	1.67E-22
Samarium-151	7.96E-22	2.73E-22	4.46E-23
Europium-152	6.04E-21	2.65E-21	4.98E-22
Gadolinium-152	3.86E-20	1.22E-20	2.51E-21
Uranium-234	3.99E-22	2.52E-22	2.78E-23
Uranium-236	3.77E-22	2.39E-22	2.63E-23
Uranium-238	3.61E-22	2.29E-22	2.52E-23
Neptunium-237	2.18E-21	9.05E-22	2.83E-22
Plutonium-239	2.81E-20	1.82E-20	3.43E-21
Plutonium-240	2.81E-20	1.82E-20	3.43E-21
Plutonium-241	3.69E-22	2.39E-22	4.49E-23
Americium-241	8.02E-20	6.99E-20	1.44E-20

Risk/y = Risk per year

The RRF for each radionuclide was multiplied by the daily flux for that radionuclide to calculate the annual contribution to lifetime risk of excess cancer morbidity. Risks for all radionuclides at all locations were then summed to yield a total daily risk.

The risk calculation includes an exposure period of 70 years. The flux is not constant. Instead, it increases with time to a maximum and then decreases again; therefore, the exposure similarly increases to a maximum and decreases again. As a result, the calculated lifetime cancer risk depends on when the exposure begins and ends. For the risk evaluation, annual risks were summed for overlapping 70-year periods beginning at the first detonation and continuing for 1,000 years. Thus, the reported risks were a 70-year sum where the first reported value is the risk from year 0 to year 70, the second is the risk from year 1 to year 71, and so forth.

Three exposure scenarios were analyzed for each combination of sites (see Section 5.6). Each scenario was analyzed by computing the RRF and the annual ingestion exposure factor. From those results, the lifetime risks for exposure of 70 years duration were calculated.

5.6 Risk Scenarios

Three dietary exposure scenarios were applied, two for subsistence diets and one for consumption of commercial catch. Within each of the two subsistence dietary exposure scenarios, there are two conditions: no kelp at Milrow and with kelp at Milrow. In addition to a base-case scenario that represents the best estimate of groundwater transport, there is a groundwater modeling sensitivity case that gives the result if there is reduced matrix diffusion. These nine groundwater scenarios are as follows:

- Combined source of Cannikin, Long Shot, and Milrow (no kelp); base-case groundwater model and sensitivity-case groundwater model
    - *Scenario 1:* Fish subsistence diet for combined Cannikin, Long Shot, and Milrow (no kelp)
    - *Scenario 2:* Marine mammal subsistence diet for combined Cannikin, Long Shot, and Milrow (no kelp)
    - *Scenario 3:* Commercial catch diet for combined Cannikin, Long Shot, and Milrow (no kelp)

- Combined source of Cannikin, Long Shot, and Milrow (with kelp); base-case groundwater model and sensitivity-case groundwater model
  - *Scenario 4:* Fish subsistence diet for combined Cannikin, Long Shot, and Milrow (with kelp)
  - *Scenario 5:* Marine mammal subsistence diet for combined Cannikin, Long Shot, and Milrow (with kelp)
  - *Scenario 6:* Commercial catch diet for combined Cannikin, Long Shot, and Milrow (with kelp)
- Combined sources in Aleut culture and communication area; base-case groundwater model and sensitivity-case groundwater model
  - *Scenario 7:* Fish subsistence diet for Aleut culture and communication area
  - *Scenario 8:* Marine mammal subsistence diet for Aleut culture and communication area
  - *Scenario 9:* Commercial catch diet for Aleut culture and communication area

To use these scenarios, an RRF was computed for each plume within each scenario. Risks for each were computed by multiplying each RRF by the modeled radionuclide fluxes. Risks for individual plumes were then summed to arrive at final cumulative risks in each scenario: (1) the sum of individual plumes, including Milrow (without kelp); (2) the sum of individual plumes, including Milrow (with kelp); and (3) the Aleut culture and communication area.

5.7 Application of Calculational Process

In the beginning of the site closure plan process, results come together from the groundwater model and the screening risk assessment (Figure 4). The results from the groundwater model are predicted locations and times of release of radionuclides. Other results of the groundwater model are possible fluxes of radionuclides entering marine water from areas of potential release on the ocean floor. Results of the screening risk assessment are modeled lifetime cancer risks from all radionuclides to human consumers eating marine food exposed to radionuclides potentially released from the Amchitka test sites.

The RRFs calculated by methods described in this report are used to calculate risks from fluxes predicted by the groundwater model. The risks from each radionuclide are summed to compute the annual risks, which are not classified because the nature and concentrations of individual radionuclides released by the blasts cannot be discerned when the risks from individual radionuclides are added together. These are the annual risks that are presented as lifetime risks by summing the annual risks for 70 years at a time.

The annual and lifetime risks are calculated for the modeled fluxes of 19 radionuclides through groundwater that would be expected from devices similar to the ones detonated at Amchitka. Calculations are made for 18 scenarios composed of various combinations of 2 groundwater flux models, 3 locations, and 3 dietary exposures. The groundwater flux model types, exposure locations, and dietary exposures are briefly described below.

Two different groundwater flux model scenarios are used to calculate the annual and lifetime risks: a base case and a sensitivity case. The base-case groundwater model represents the best estimate of groundwater model parameters. The sensitivity-case model represents radionuclide fluxes with reduced matrix diffusion, which means that some radionuclides are allowed to move rapidly and spread out less than the best estimates of parameters predict. Some aspects of the groundwater models are uncertain, due to data limitations and the natural spatial variability of the subsurface. This uncertainty is included in the groundwater models and is expressed as a standard deviation around the mean fluxes. The mean flux of the base-case model is the best estimate; by adding the standard deviation to the mean, a conservative estimate (meaning allowing higher fluxes) is obtained that accounts for uncertainty in our estimate of the mean. The same is done for the sensitivity case where the mean flux of this case can be compared to the base-case model to show the impact of matrix diffusion reduction, and by adding the standard deviation to this mean, the conservative estimate sensitivity to matrix diffusion is evaluated. It is important to realize that subtracting the standard deviation is equally valid for evaluating uncertainty as adding the standard deviation to the mean results. When the standard deviation is subtracted, no radionuclides from the tests reach the seafloor in any of the model calculations.

The estimated daily fluxes of radionuclides from the three tests are averaged for each of 1,000 years after the first test in 1965. The annual averages are multiplied by RRFs (Section 5.5) to obtain the annual risk for each radionuclide and for each test. All of the risks for a given year are then summed to obtain a single annual risk for each scenario.

Seventy-year cumulative risk values (lifetime risks to human health for developing cancer) are calculated by summing the annual risks for 70-year intervals, beginning with each successive year of model output. Thus, the value shown as the 70-year cumulative risk for the year 1965 is the risk for a lifetime exposure that began in 1965 and will end in 2034. This value is referred to hereafter as the "lifetime risk."

As shown above, three dilution scenarios are evaluated for calculating the annual and lifetime predicted risks: (1) Cannikin, Long Shot, and Milrow (no kelp); (2) Cannikin, Long Shot, and Milrow (with kelp); and (3) Aleut culture and communication area. The risk scenarios to human health from the 19 radionuclides are presented for both groundwater flux model scenarios and all 3 dilution scenarios.

The dietary exposure scenarios used to calculate the annual and lifetime risks include fish subsistence consumption, marine mammal subsistence consumption, and commercial catch consumption. The risks for each of the three dietary exposure scenarios are calculated for all three dilution scenarios for a total of nine risk scenarios. Predicted annual risks and predicted lifetime risks for all scenarios are presented in Section 5.8. The nine human health risk scenarios that are evaluated in this report were listed previously, showing their combinations of sources, groundwater flux model type, and dietary exposure scenarios.

Plots of the annual risk values for the mean radionuclide fluxes are prepared. These plots show the time elapsed since the first detonation (in years) on the x-axis and the annual excess cancer risk on the y-axis. However, the plots of annual risk values for mean radionuclide flux only show the narrower time frame between 0 and 100 years after detonations. The narrower range of years is chosen so the smaller scale enhances visualization of how the annual risk for mean radionuclide flux increased from 0 at time of the first detonation (1965) to the maximum risk value in relation to the present time (2002).

Plots of the lifetime risk values for the mean flux and the mean plus 2 standard deviations are prepared for each of the 18 risk scenarios. The plots show the time elapsed since the first detonation (in years) on the x-axis (0 to 1,000 years), and lifetime excess cancer risk on the y-axis (log scale). The lifetime excess cancer risk values are unitless probabilities that someone in the population will develop cancer during a 70-year lifetime as a result of lifelong exposure to radionuclides from the Amchitka devices. For example, a lifetime excess cancer risk value of 1.0×10^{-5} represents a probability that 1 person out of 100,000 will develop cancer as a result of exposure to Amchitka radionuclides during a 70-year lifetime. This is also equivalent to saying that the probability of a given person developing cancer is 1.0×10^{-5} more than the usual population frequency of cancer. The U.S. Environmental Protection Agency's (EPA's) "point of departure" for risk, 1.0×10^{-6} (EPA, 1998) is also shown on the plots. This value represents EPA's lower limit of concern for carcinogens and the threshold below which EPA considers the risks to be undetectable. If the average lifetime risks are below 1.0×10^{-6}, EPA typically will not require further action. EPA's upper bound for average lifetime risk is 1.0×10^{-4} (EPA, 1998). The upper bound for average lifetime risk represents the threshold above which EPA considers the risks to be unacceptable and will likely require further action to reduce the risks to acceptable levels. Conditions that result in lifetime risks between 1.0×10^{-6} and 1.0×10^{-4} require further consideration of the need to reduce risks.

5.8 Findings

This section discusses the plots and written narratives of the predicted annual risk values for the mean radionuclide fluxes. In addition, the plots of the predicted lifetime risk values for the mean radionuclide flux and the mean plus 2 standard deviations that were prepared for each of the nine risk scenarios are discussed. The discussions focus on describing the predicted maximum lifetime risk values for the mean radionuclide flux and the mean plus 2 standard deviations for each of the nine scenarios and comparing those maximum values to EPA's point of departure for risk value of 1.0×10^{-6}. The discussions also indicate the years in which the predicted maximum lifetime risk values occur and their relation to the present year (2002).

In each scenario, results are first presented for the groundwater model base case, whose mean is the best estimate of risk. The base case is followed by the groundwater model sensitivity case, in which radionuclides are not retarded by their expected interaction with the subsurface.

5.8.1 Scenario 1: Fish Subsistence Diet for Combined Source of Cannikin, Long Shot, and Milrow (No Kelp)

5.8.1.1 Base Case

A plot of the modeled lifetime risk values for the mean radionuclide flux for the fish subsistence dietary exposure scenario for the combined source of Cannikin, Long Shot, and Milrow (no kelp), base-case groundwater model, along with the plot for the mean plus 2 standard deviations, is shown in Figure 5A for the entire modeled period. The maximum lifetime risk value for the mean radionuclide flux was 9.7×10^{-11} lifetime excess cancer risk (Table 7), which is more than

Table 7
Summary of Maximum Risk Values and the Calendar Year in Which Those Maximum Values Occur for Each of the 9 Risk Scenarios Based on Combinations of Groundwater Model Type, Dietary Exposure, and Location
(Page 1 of 2)

Groundwater Model Type, Dietary Exposure, and Location Scenarios	Base-Case Groundwater Model Scenarios			Sensitivity-Case Groundwater Model Scenarios		
	Maximum Lifetime Risk Values for Mean Radionuclide Flux	Maximum Lifetime Risk Values for Mean Radionuclide Flux + 2 S.D.	Calendar Year When Exposure Began for Maximum Lifetime Risk for Mean Radionuclide Flux	Maximum Lifetime Risk Values for Mean Radionuclide Flux	Maximum Lifetime Risk Values for Mean Radionuclide Flux + 2 S.D.	Calendar Year When Exposure Began for Maximum Lifetime Risk or Mean Radionuclide Flux
Scenario 1: Fish subsistence diet exposure at the combined Cannikin, Long Shot, and Milrow (no kelp) location	9.7E-11	1.6E-09	1994	1.7E-08	1.8E-07	1968
Scenario 2: Mammal subsistence diet exposure at the combined Cannikin, Long Shot, and Milrow (no kelp) location	5.3E-11	8.9E-10	1990	9.7E-09	9.4E-08	1968
Scenario 3: Commercial catch diet exposure at the combined Cannikin, Long Shot, and Milrow (no kelp) location	4.2E-12	7.0E-11	1993	7.4E-10	7.2E-09	1968
Scenario 4: Fish subsistence diet exposure at the combined Cannikin, Long Shot, and Milrow (with kelp) location	9.7E-11	1.6E-09	1994	1.9E-08	2.3E-07	1968
Scenario 5: Mammal subsistence diet exposure at the combined Cannikin, Long Shot, and Milrow (with kelp) location	5.3E-11	8.9E-10	1990	1.1E-08	1.3E-07	1968
Scenario 6: Commercial catch diet exposure at the combined Cannikin, Long Shot, and Milrow (with kelp) location	4.2E-12	7.0E-11	1993	7.9E-10	8.7E-09	1968
Scenario 7: Fish subsistence diet exposure at the Aleut culture and communication area location	2.1E-11	3.4E-10	1994	3.5E-09	3.5E-08	1968

Table 7
Summary of Maximum Risk Values and the Calendar Year in Which Those Maximum Values Occur for Each of the 9 Risk Scenarios Based on Combinations of Groundwater Model Type, Dietary Exposure, and Location
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Groundwater Model Type, Dietary Exposure, and Location Scenarios	Base-Case Groundwater Model Scenarios			Sensitivity-Case Groundwater Model Scenarios		
	Maximum Lifetime Risk Values for Mean Radionuclide Flux	Maximum Lifetime Risk Values for Mean Radionuclide Flux + 2 S.D.	Calendar Year When Exposure Began for Maximum Lifetime Risk for Mean Radionuclide Flux	Maximum Lifetime Risk Values for Mean Radionuclide Flux	Maximum Lifetime Risk Values for Mean Radionuclide Flux + 2 S.D.	Calendar Year When Exposure Began for Maximum Lifetime Risk or Mean Radionuclide Flux
Scenario 8: Mammal subsistence diet exposure at the Aleut culture and communication area location	1.1E-11	1.9E-10	1990	2.0E-09	1.9E-08	1968
Scenario 9: Commercial catch diet exposure at the Aleut culture and communication area location	8.9E-13	1.5E-11	1993	1.5E-10	1.4E-09	1968

S.D. = Standard deviations

10,000-fold lower than EPA's point of departure for risk of 1.0×10^{-6}. The maximum lifetime risk value for the mean radionuclide flux plus 2 standard deviations was 1.6×10^{-9} (Table 7), which is more than 500-fold lower than the EPA's point of departure for risk.

The maximum modeled lifetime risk for the mean radionuclide flux was for a 70-year lifetime of exposure that began in 1994. Lifetime risks are predicted to have decreased for exposures that have begun since that year to the current value of 9.6×10^{-11}, and will continue to decrease in the future (Figure 5A).

5.8.1.2 Groundwater Modeling Sensitivity Case

A plot of the modeled lifetime risk values for the mean radionuclide flux for the fish subsistence dietary exposure scenario for the combined source of Cannikin, Long Shot, and Milrow (no kelp), sensitivity-case groundwater model, along with the plot for the mean plus 2 standard deviations, is shown in Figure 5B for the entire modeled period. The maximum lifetime risk value for the mean radionuclide flux was 1.7×10^{-8} lifetime excess cancer risk (Table 7), which is more than 50-fold lower than EPA's point of departure for risk of 1.0×10^{-6}. The maximum lifetime risk value for the mean radionuclide flux plus 2 standard deviations was 1.8×10^{-7} (Table 7), which is more than 5-fold lower than the EPA's point of departure for risk.

The maximum modeled lifetime risk for the mean radionuclide flux was for exposure that began in 1968. Lifetime risks are predicted to have decreased for exposures that have begun since that year to the current value of 8.4×10^{-9}, and will continue to decrease in the future (Figure 5B).

5.8.1.3 Conclusion

All of the modeled lifetime risk values for the mean radionuclide flux (as well as the mean plus 2 standard deviation values) during the entire 1,000-year period evaluated for this dietary exposure, location, and base-case and sensitivity-case models are below EPA's point of departure for risk.